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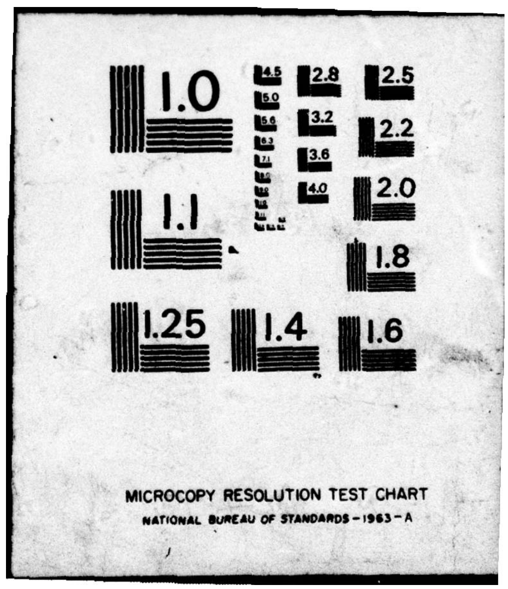
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Special Report 76-15

FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

First Year Progress Report

C. Collins
F. Deneke
T. Jenkins
L. Johnson
T. McFadden
C. Slaughter
E. Sparrow

November 1976

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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The long-term effects and ultimate fate of crude oil spilled on permafrost-underlain tundra is the subject of this study. The project involves two experimental oil spills of 2000 gallons (7570 liters) each on 500-m^2 test plots near Fairbanks, Alaska. A winter spill, discussed in this ~~progress~~ report, took place in February 1976. Another spill will take place at the peak of the growing season in the summer. This allows conditions prevailing during these climatic periods to be studied as to their effect on oil spills, and makes it

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possible to study the reaction of the spilled oil to these temperature extremes. The February spill ~~discussed in this report was~~ designed to simulate a real pipeline leak, ~~and~~ was large enough to approach reality while remaining within the limits of logistical capabilities. Monitoring ~~of~~ the spill and control plots includes: oil movement, temperature regime, biological effects, microbiological changes, permafrost impact, and chemical degradation of the oil.

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FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

First Year Progress Report

by

C. Collins, F. Deneke, T. Jenkins, L. Johnson
T. McFadden, C. Slaughter and E. Sparrow

Introduction

Under the sponsorship of the Environmental Protection Agency, the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory, has initiated a study to evaluate the fate and effects of crude oil on a permafrost taiga site in interior Alaska.

Crude oil to be transported by the Trans-Alaska pipeline will be 60^{o}-74^{o}C (140^{o}-165^{o}F). For this study Prudhoe Bay crude oil is being heated and applied to undisturbed sites underlain by permafrost. Both summer and winter spills are possible; and since each may have different characteristics, the project was designed to evaluate both. Study of oil fractionation and breakdown over time, thermal effects in the soil mantle, effects on vegetation, and microbiological aspects are included in the project.

Summary of study plan

The basic plan is to apply hot oil to instrumented plots during both summer and winter, and monitor thermal changes, oil movement, changes in oil composition, microbiological effects and plant response. A realistic simulation of possible oil spill conditions called for relatively large quantities of oil, applied rapidly over a small area. The experimental design formulated consisted of three study plots, each 10 m × 50 m with the long axis downslope. One plot was to be designated control, and was located upslope from the other two to avoid the possibility of contamination from treated plots. Two treated plots, one for winter and one for summer, were designated. At each, 7570 liters (2000 gal) of hot oil was to be applied along a 5-m-wide front at the top edge of the plot. Pre-treatment site characterization included vegetation, soil, and microbiological analysis. Instrumentation for monitoring thermal responses was installed prior to the treatment. The final study area layout is shown in Figure 2.

Results to date

1. Site selection. Final site selection was completed in July 1975. The study site chosen lies in the lower reaches of the Caribou-Poker Creeks Research Watershed, 48 km (30 miles) north of Fairbanks, Alaska (Fig. 1). It has a moderate (7-8%) west facing slope. The study plots were located, boundaries flagged, and a plane-table map of the area prepared (Fig. 2).

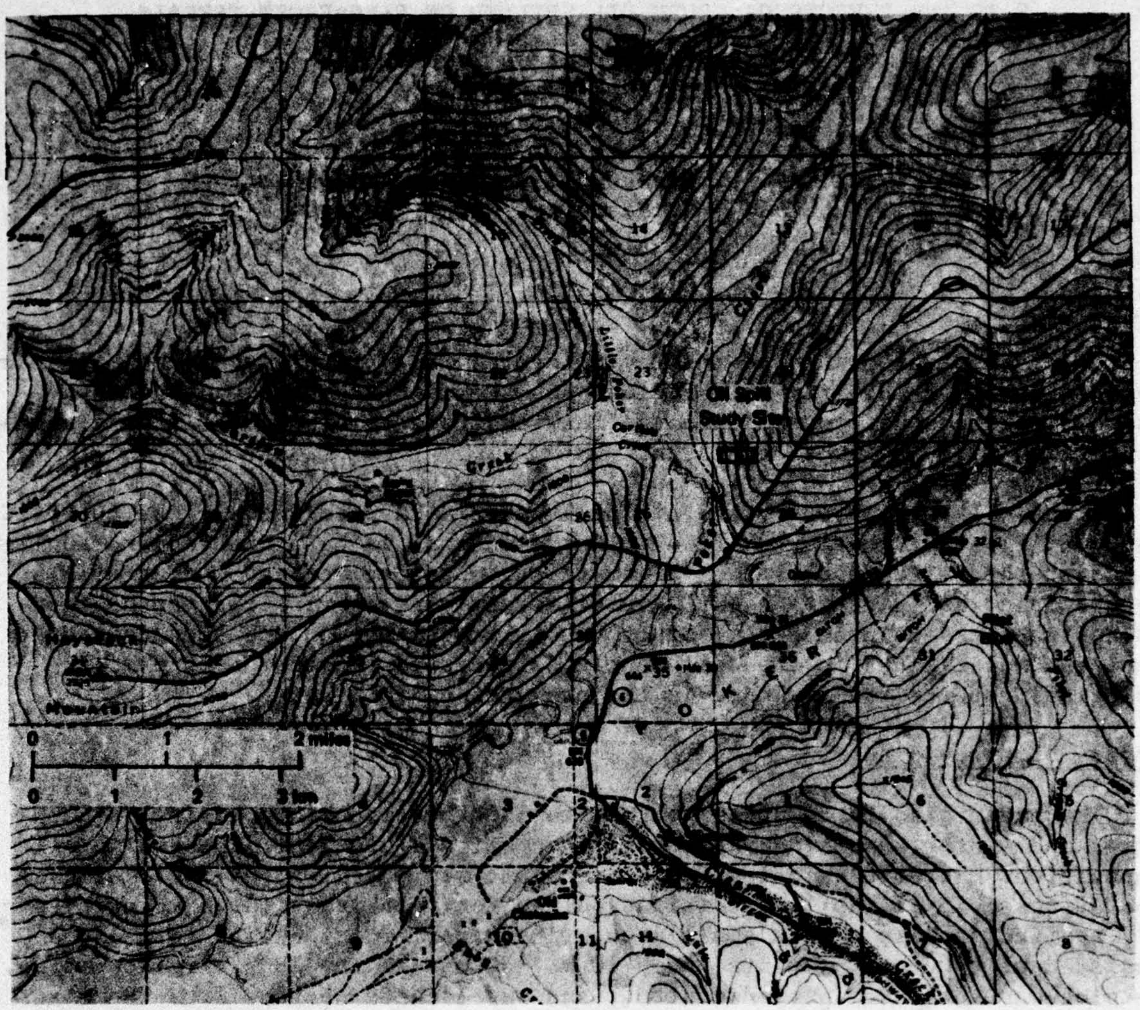


Figure 1. Study area in Caribou-Poker Creeks research watershed.

The area is approximately 300 m (1000 ft) above sea level; the nearest watercourse is Poker Creek, approximately 800 m (900 yards) to the west. The Chatanika River, into which Poker Creek flows, is approximately 2.4 km (1½ miles) to the south. An abandoned water diversion ditch built in 1910 lies between the oil study site and Poker Creek, providing a guard against possible oil contamination of Poker Creek.

2. Soils. The initial site characterization task, plane table mapping, was followed by soils, vegetation, and microbiological classification. Soils are classified as Saulich silt loam (Rieger et al. 1972). The Saulich series consists of poorly drained soils on the foot slopes of hills; the soils are almost always wet and have shallow permafrost. They differ from Ester soils in that they are deeper over bedrock and are not as acid. A representative profile of Saulich silt loam taken about 1.3 miles west of Caribou Creek is given in Table I.

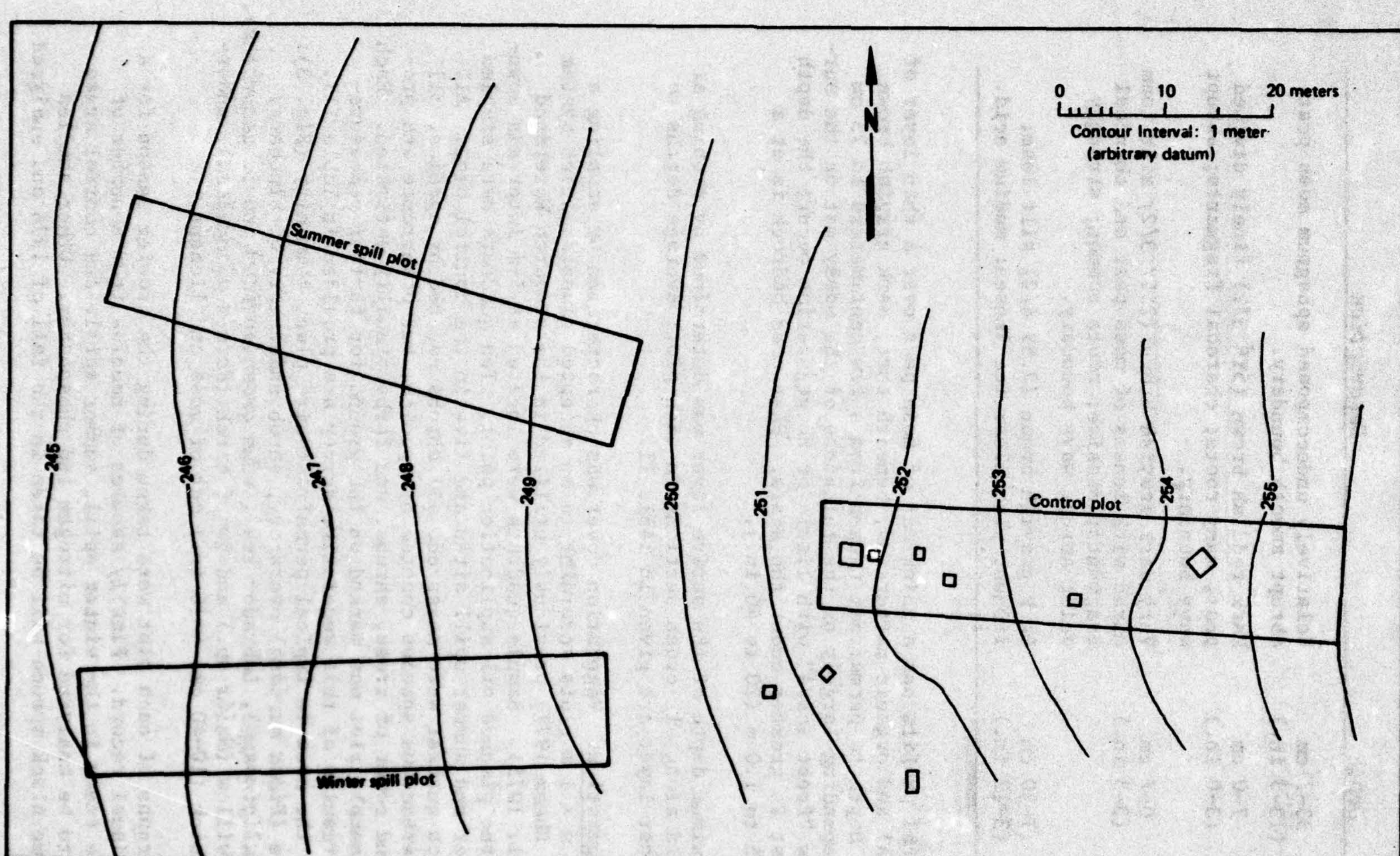


Figure 2. Layout of oil spill plots in study area.

Table I. Profile of Saulich silt loam.

Horizon	*Depth*	*Description*
O1	33-7 cm (13-3 in.)	Relatively undecomposed sphagnum moss peat; abrupt smooth boundary.
O2	7-0 cm (3-0 in.)	Dark reddish brown (5YR 3/2) finely divided peat; many roots; charcoal fragments; abrupt wavy boundary.
A1	0-7 cm (0-3 in.)	Very dark grayish brown (2.5Y 3/2) silt loam mixed with lenses of moss peat and charcoal fragments; massive; roots common; strongly acid; abrupt wavy boundary.
C2f	7-30 cm (3-12 in.)	Dark grayish brown (2.5Y 4/2) silt loam; frozen, with clear ice lenses; medium acid.

A typical profile has a thick mat of moss peat over a thin layer of mixed mineral and organic matter and, beneath that, dark grayish brown silt loam. Depth to permafrost ranges from a few centimeters to 75 cm (30 in.), depending largely on the thickness of the mossy mat on the surface. A few "frost scars" with little or no vegetation occur; the depth to permafrost is greater under the scars. Shattered bedrock is at a depth of 0.5 to 1.0 m (20 to 40 in.).

The maximum depth of the active layer was determined by probing at 1-m intervals along six cross sections in each plot; average depths to the permafrost layer are given in Table II.

<u>3. Vegetation</u>. Vegetation cover was characterized by sampling a number of 1 m × 1 m plots according to an accepted classification system (Ohmann and Rheam 1971) previously utilized in the Research Watershed (Troth et al. 1975). Sample quadrats were located at 5-m intervals downslope from the planned oil application point. Ten quadrats were sampled in the winter and summer spill sites and five in the control plot. All trees in each quadrat were measured, all shrubs counted by species, all forbs and herbaceous species counted by species, and occurrence and projected ground cover of trees, shrubs, and forbs visually estimated. Each vegetation sample plot was marked on the ground for further remeasurement. The results of this vegetative survey are provided in Table III. Essentially the area is typical permafrost-site plant community (Fig. 3): black spruce (*Picea mariana*) overstory; shrub understory of blueberry (*Vaccinium uliginosum*), Labrador tea (*Ledum groenlandicum* and *L. decumbens*), occasional willow (*Salix* sp.) and dwarf birch (*Betula glandulosa*), underlain by a thick (10-40 cm; 4-16 in.) mat of moss and lichens.

Photographs of each plot were taken during the growing season for a permanent visual record. Finally samples of needles from a number of black spruce trees in the winter spill, summer spill, and control areas were taken to be analyzed for nitrogen and phosphorus. Other samples from the same black spruce will be taken in the fall of 1976 and analyzed

Table II. Depth (cm) of active layer to permafrost in winter oil spill plot, July 1976.

Distance from top edge (m)	*Distance from south edge (m)* 0	1	2	3	4	5	6	7	8	9	10
20 July											
1	40	56	64	35	35	44	50	31	32	41	42
3	31	34	37	44	51	44	52	43	45	44	39
6	41	31	34	65	59	42	30	41	31	48	41
9	44	42	42	33	29	31	44	41	41	37	51
14	31	29	31	25	31	24	28	39	46	34	44
20	37	33	34	41	47	26	27	25	26	40	41
26 July											
1	41	63	67	38	39	47	51	35	41	45	44
3	35	38	42	48	55	51	52	45	50	46	43
6	45	31	38	67	61	44	38	45	40	51	46
9	46	47	45	33	35	38	46	44	38	35	47
14	35	33	36	30	36	31	33	40	50	36	42
20	42	41	36	50	47	28	30	32	30	43	41

for N and P to determine if there are any significant changes in nutrient content associated with the trees near the spill sites.

4. Physical preparations. Elevated crosswalks were installed at 5-m intervals across the treatment plots to allow direct access to the plots while minimizing surface trampling and disturbances (Fig. 3). Aluminum I-beams were supported on timber blocking.

An extensive thermocouple array was designed and installed in the plots. Temperature measurement was desired at five levels (Fig. 4), from within the permafrost up to the overlying moss/lichen ground cover. This vertical array was replicated 36 times (Fig. 5), to allow adequate spatial monitoring of thermal effects. Thermocouple leads were connected to centrally located switches, facilitating manual read-outs. Measurement of the soil temperature regimen was initiated 6 Aug 75. Temperature trends for selected thermocouple arrays are given in Figure 6.

"Oil detection stakes," 32-mm (1¼-in.) wooden dowels, were inserted into the soil (Fig. 5). Rapid absorption of any oil reaching the untreated wood of the dowel can be readily detected either visually, by smell, or with a fluorescent light.

A station for monitoring local climate was installed by the Fort Wainwright Detachment, Meteorological Support Command. Air temperature, ground temperature in the moss, wind run, and precipitation are monitored (Fig. 7).

Table III. Results of initial vegetation analysis and soil thaw measuring - winter treatment (spill) and control plots.

Live ground cover - total		Frequency of occurrence (%) Spill	Frequency of occurrence (%) Control	*Cover class (range) Spill	*Cover class (range) Control	Aug thaw Spill	Aug thaw Control	No. of individuals (range) Spill	No. of individuals (range) Control
Trees	*Picea mariana*	80	60	0-8	1-5	26	32	0-7	1-4
	Rubus chamaemorus	70	100	0-2	2-3	25	33	0-15	16-54
Dwarf	*Equisetum sylvaticum*	80	40	1-2		37	31		
shrubs and	*Petasites hyperboreus*	30	100	1-2	1-3	28	49	1-3	1-20
herbs	*Eriophorum vaginatum*	100	60	1-5	1-2	27	40		
	Grammea spp.		40	1					
Mosses	Total	100	100	4-7	6-8	33			
	Pleurozium schreberi	100	100	3-6	4-6	37			
	Polytrichum spp.	100	100	1-3	1-2	30			
	Dicranum spp.	80	80	1-2	1-3	28			
	Sphagnum spp.	40	40	1-5	5-6	35			
	Other	10		1					
Lichens	Total	100	100	3-6	4-6				
	Foliose	100	100	1-4	1-3				
	Fruticose	100	100	3-6	4-6				
	Cladonia spp.	100	100	3-6	4-6				
	Cetraria spp.	100	100	1-3	1-4				
	Peltigera spp.	100	100	1-3	1-3				
Mushrooms		10		1					
Medium and	*Betula glandulosa*	90	60	1-3	1-4			1-14	1-27
low shrubs	*Ledum decumbens*	70		1-3				4-122	
	Ledum groenlandicum	80	100	1-4	2-4			6-96	25-86
	Vaccinium uliginosum	100	100	1-4	2-5			8-135	35-138
	Vaccinium vitis-idaea	100	100	2-5	3-5				

*Cover classes: 1: present 3: 6-10% 5: 21-40% 7: 61-80%
2: 1-5% 4: 11-20% 6: 41-60% 8: 81-100%

Figure 3. Typical permafrost plant community.

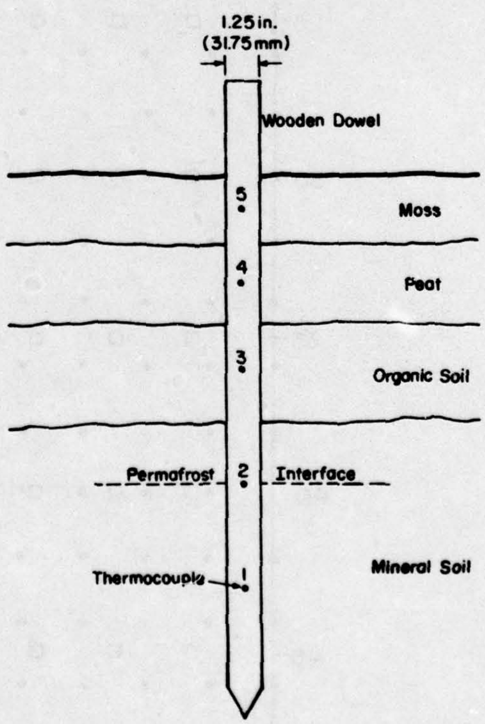


Figure 4. Thermocouple levels.

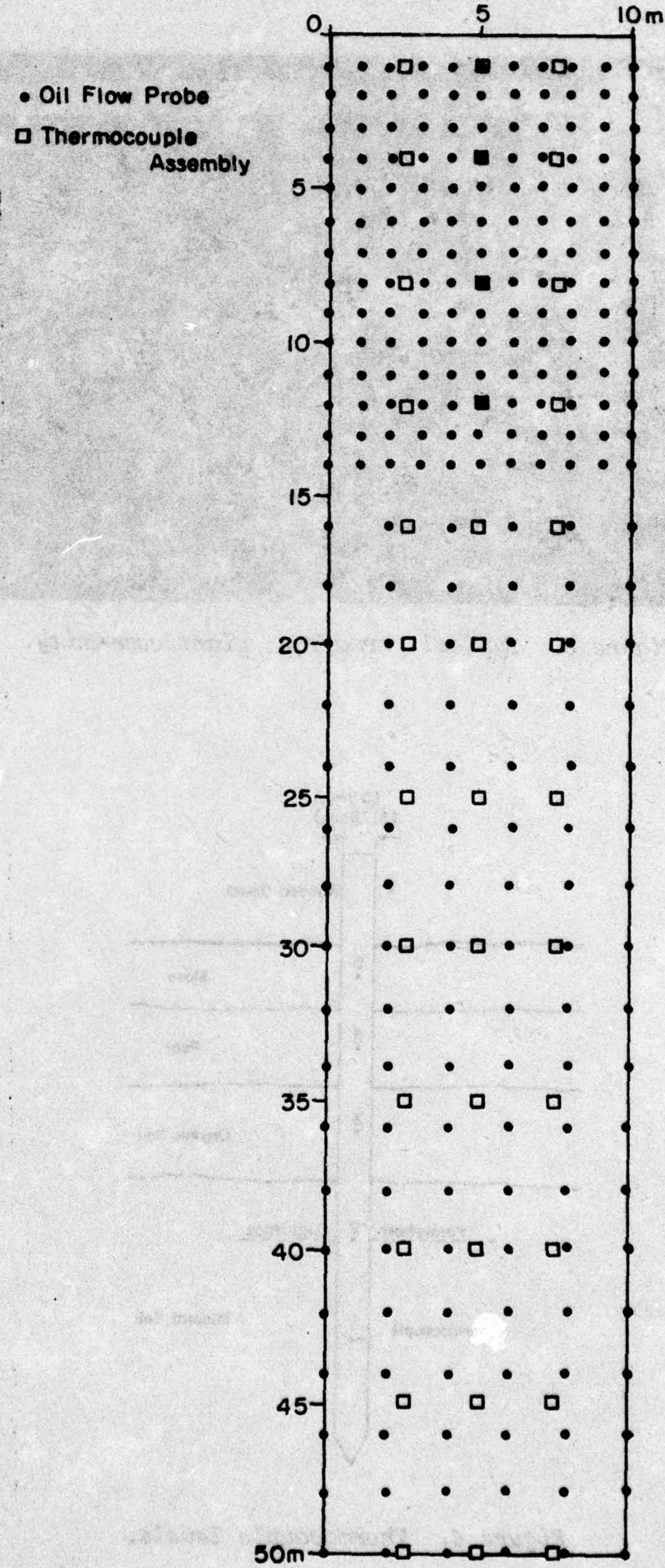


Figure 5. Layout of oil detection stakes and thermocouple arrays.

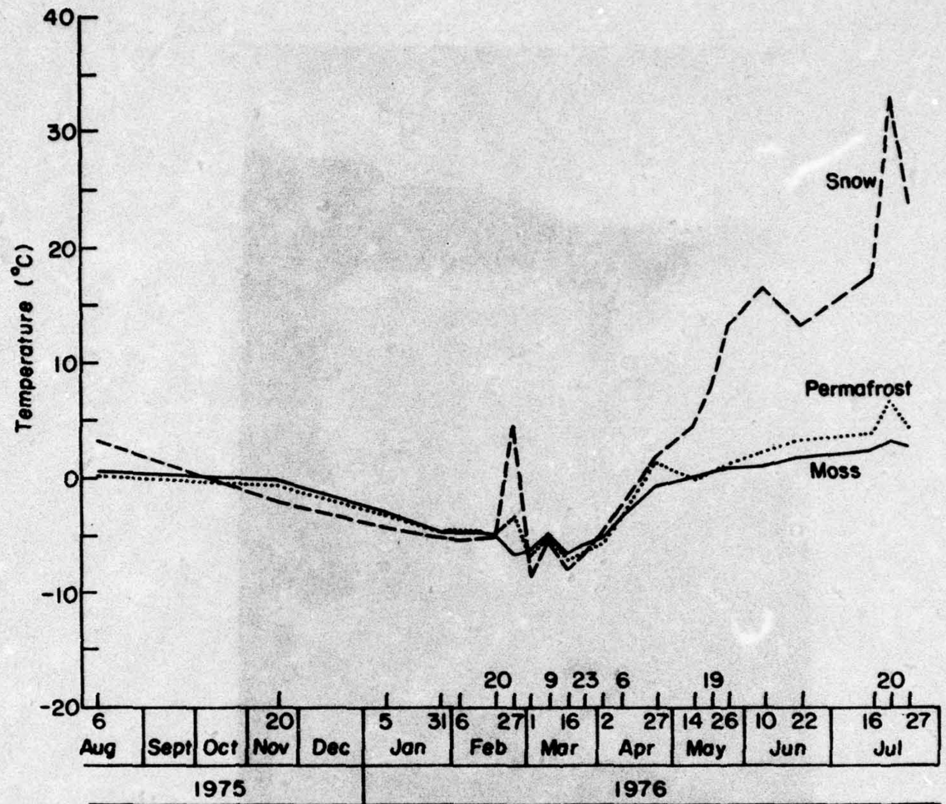


Figure 6. Temperature trends for selected thermocouple arrays.

Figure 7. Climatic station.

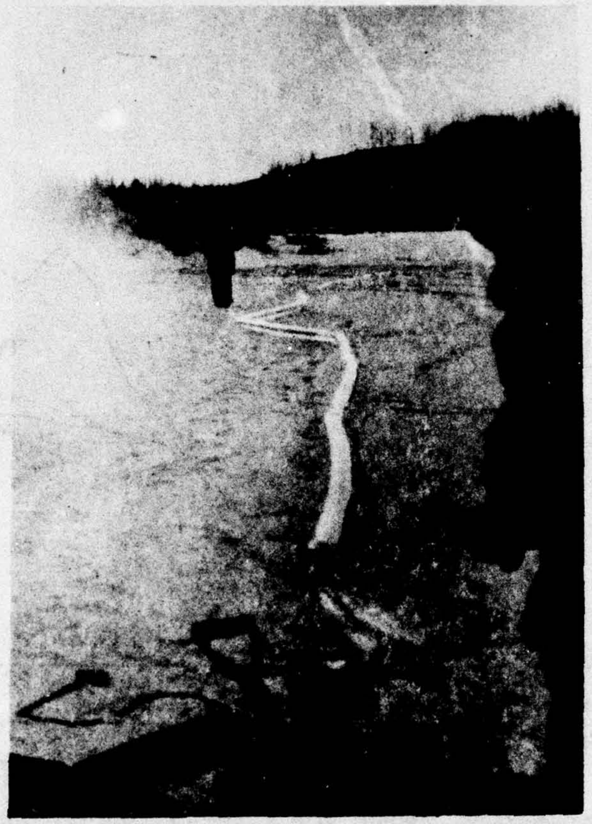


Figure 8. Ice bridge across Chatanika River.

Access to the study area was improved during summer and fall. A bridge was built, crossing the abandoned water ditch downslope from the study site, and a trail and turn-around cleared to the south side and top of the study area. Following freeze-up, an ice bridge was constructed on the Chatanika River (Fig. 8), and 300 m^3 (400 yd^3) of gravel was spread on the primary access trail to the research watershed. This allows access to the site by 4-wheel-drive vehicles during times when the Chatanika River is fordable or has adequate ice cover.

Oil for this project was obtained from Prudhoe Bay. It was shipped by truck in 55-gallon drums, which were stockpiled at the Poker Flats Rocket Range. A physical analysis of the oil is provided in Figure 9.

Transportation and heating of the crude oil for application received major effort. The concept of airlifting the oil, in a bulk tank, directly to the study site by "sky crane" helicopter was considered but finally rejected. Problems foreseen included site disturbance by the strong downblast of the helicopter rotors (which would undoubtedly have removed much of the snow cover in winter and many site markers) and vulnerability to weather fluctuations. The method utilized was to mount a 2000-gallon (7570-liter) bulk tank on an RN-110 Nodwell tracked vehicle (Fig. 10a). This tank was externally insulated with 7½ cm (3 in.) of fiberglass to minimize heat loss and maintain oil temperature. Heat was provided by

Company U.S. Army Cold Regions Research and Engineering Lab.	Date May 4, 1976 Lab. No. 4121
Well No.	Location
Field North Slope	Formation
County	Depth
State Alaska	Analyzed by To

PRUDHOE CRUDE OIL

GENERAL CHARACTERISTICS

Specific gravity @ 60/60 °F.	
A.P.I. gravity @ 60 °F.	37.7
Saybolt Universal Viscosity @ 70°F., seconds	198.5
Saybolt Universal Viscosity @ 100°F., seconds	89.9
B. s. and water, % by volume	0.6
Pour point, °F.	0
Total sulphur, % by weight	1.0

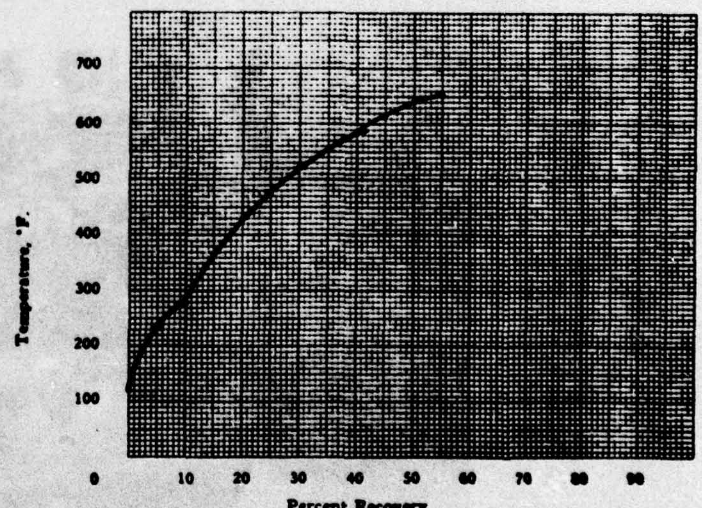
REMARKS: Thermal Cracking Point at 654°F

ENGLER DISTILLATION

Recovery, %	Temperature, °F.
IBP	122
5	235
10	280
15	368
20	430
25	478
30	524
35	556
40	586
45	618
50	646
55 Thermal Cracking Point	654
60	
65	
70	
75	
80	
85	
90	
95	
E.P.	

Recovery, %	55
Residue, %	45
Loss, %	0

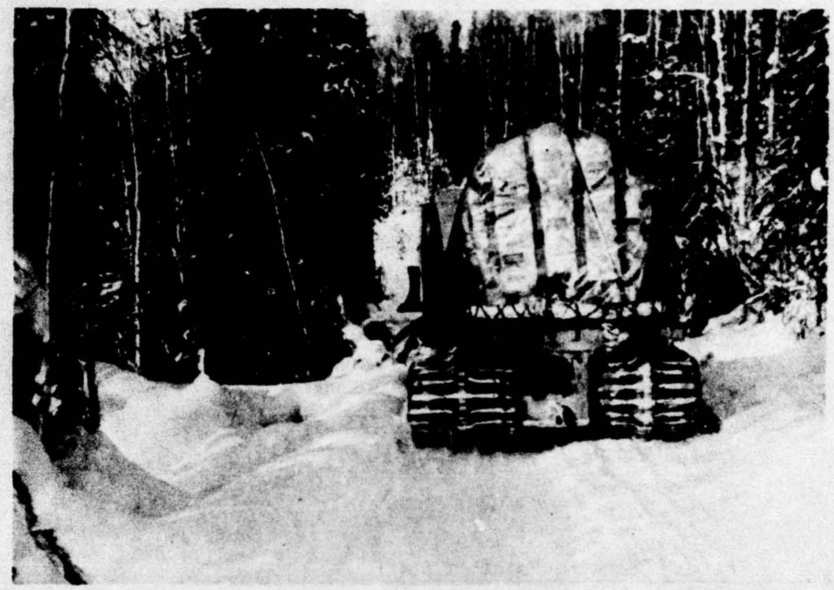
DISTILLATION GRAPH



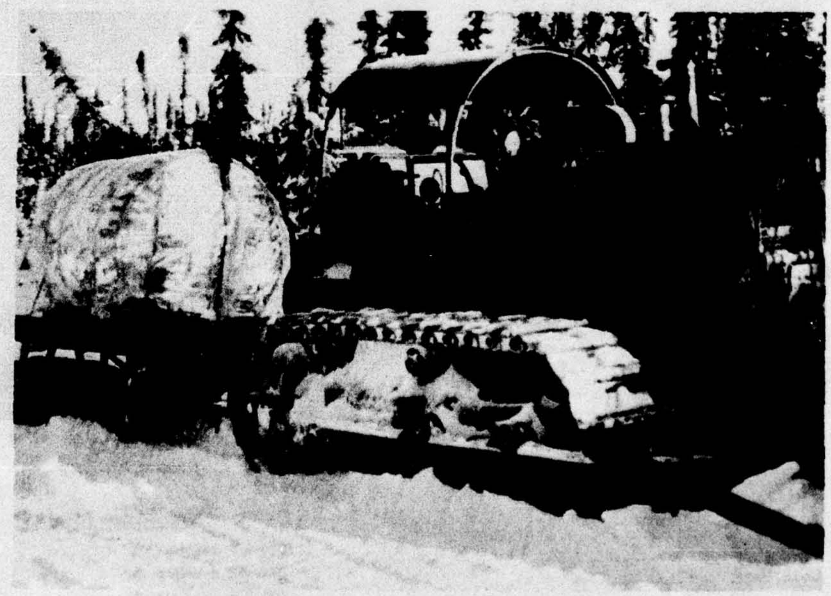
Approximate Recovery

300 EP gasoline, %	11
392 EP gasoline, %	18
500 EP distillate, %	10

Figure 9. Physical analysis of crude oil.



a. RN-110 Nodwell with tank.



b. Second tank on trailer.

Figure 10. Oil tanks mounted on RN-110 Nodwell and trailer.

two 750-watt heating cables suspended in the tank and six 75-watt heating tapes encircling the tank beneath the insulation.

Since it was determined that a full 2000-gal. tank would far exceed the load capacity of the Nodwell, a second tank of 1000 gallons (3785 liters) capacity was mounted on a tracked trailer and similarly insulated (Fig. 10b).

The bulk tank on the Nodwell was equipped with valves and electric pumps to allow pumping both into and out of the tank, or to allow emptying by gravity feed. For actual oil application, a "header" was fabricated from 10-cm (4-in.)-ID pipe. This 5-m-long pipe was sealed at each end and perforated at 10-cm (4-in.) intervals along one side for release of the oil. The intake was centered on the back side of the pipe. Transfer from tank to header was through 7½-cm (3-in.)-ID flexible hose, insulated for heat retention.

Physical procedures

Several weeks prior to the winter treatment, 2000 gallons (7570 liters) of oil, still in 55-gallon drums, was moved to warm storage at the CRREL Alaskan Projects Office in Fairbanks. After it had warmed to room temperature, the oil was transferred to the Nodwell-mounted tank; the full tank was then heated (while still parked in a warm garage) by the electrical heating tapes, previously described, to an oil temperature of 63°C (145°F). The loaded Nodwell was then transported by "lo-boy" trailer to Poker Flats where heating elements were reconnected to line power. At Poker Flats half the oil was then transferred to the smaller trailer-mounted tank for final movement to the site. On 21 February two 5-kW generators were moved to the study site for use in maintaining oil temperature, operating pumps, etc. On 23 February the Nodwell and the trailer with their respective loads of hot oil were moved to the study site. The oil in the trailer was transferred back to the Nodwell.

Winter oil spill

The winter spill was applied 26 February 1976. Snow depth on the plot was approximately 45 cm (18 in.). At the time of treatment (1145 AST) the air temperature was -5°C (23°F) and the wind was calm. The oil was applied on a 5-m front (Fig. 11) at the upper end of the winter treatment plot. The temperature of the oil when it left the header was 57°C (135°F). 2000 gallons (7570 liters) was applied by gravity feed in 45 minutes for a flow rate of 44.5 gallons per minute (168.2 liters per minute).

As expected, the heated oil followed the microrelief of the frozen soil surface underlying the snow and moss. In the immediate vicinity of the point of application snow collapse was rapid, a result of both oil saturation and melt from the heat (Fig. 12).

For the first few hours following treatment, oil moved downslope under the snowpack in the moss overlying the frozen silt; the oil's position was detected by probing with a wooden lath. The presence of the oil

Figure 11. Oil application.

Figure 12. Snow collapse during application.

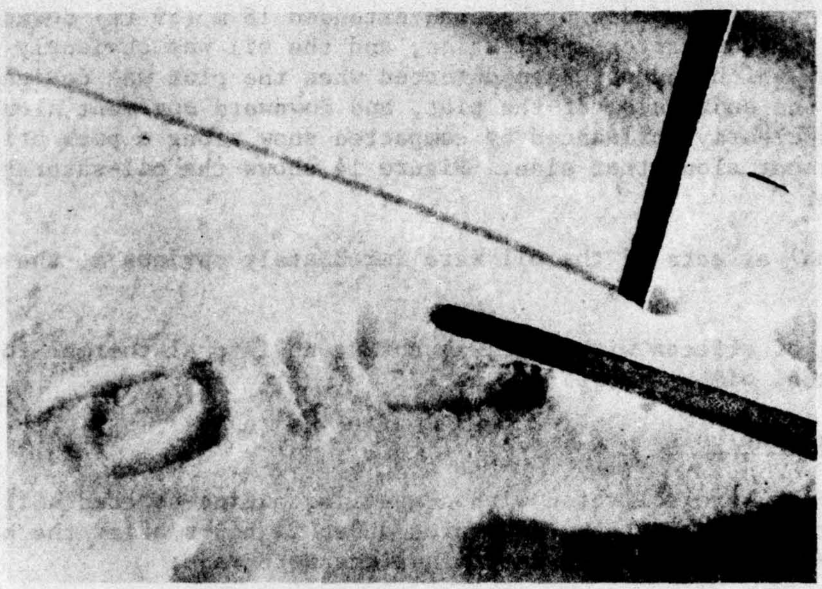


Figure 13. Oil on wooden probe.

Figure 14. Oil-saturated snow/moss interface.

was readily discerned by sight and smell on clean wood (Fig. 13). Oil spread, as detected by wooden probe, had extended 18 m (59 ft) downslope approximately 24 hours after application, and the oil was obviously following microrelief which had not been detected when the plot was designed. Spread was to the south side of the plot, and downward movement along the south side was clearly influenced by compacted snow along a path utilized prior to treatment along that side. Figure 14 shows the oil-saturated snow/moss interface.

The thermal effects of the oil were immediately obvious at the application point.

A damping of effects with time was noted; no lateral thermal influence (away from actual oil presence) was noted.

Microbiological analysis

Soil samples were collected with a gasoline engine-powered soil corer from the control plot and the winter plot about 24 hours after the heated oil was applied. The following determinations were made:

1. Soil pH
2. Soil moisture
3. Bacterial population - viable cell count on plate count agar
4. Fungal population - viable cell count on Martin's medium
5. Proteolytic microorganisms on Frazier Gelatin medium
6. Cellulolytic microorganisms on Bushnell & Haas Cellulose Silica Gel medium
7. Hydrocarbon degraders on Bushnell & Haas Cab-O-Silica Gel medium
8. Enrichments for hydrocarbon degraders
9. Nitrifiers by multiple tube (MNP) method
10. Soil respiration-carbon dioxide evolution of soils in biometer flasks
11. Oil analysis of the enrichment cultures

For items 3 to 10, two incubation temperatures (4^{o} and 20^{o}C) were employed. Portions of the soil samples were set aside and frozen for future nutrient analysis. The results of the soil pH and soil moisture measurements are shown in Tables IV and V. There is a 0.7 unit increase in soil pH in the duff layer of the winter oil plot. Microbiological analysis has not been fully completed. From preliminary examination of the available data, oil had neither a stimulatory nor an adverse effect on bacterial and fungal populations. However, oil seemed to have an inhibitory effect on soil respiration. Carbon dioxide evolved from soil samples taken from the winter plot (oiled) was half that evolved from soil samples taken from the control plot (unoiled). The data will be statistically analyzed.

Chemical analysis

Samples of oil were collected during the winter spill and returned to CRREL (Hanover) for analysis. Initial fractionation indicated that 25% of the oil was lost during the topping procedure which corresponds to the volatile fraction of the oil. When the remainder was fractionated, 39.7% was found to be alkane, 28.5% aromatic, 12% asphaltene, and 19.8%

Table IV. Soil pH, one day after winter oil treatment.

Soil layer	*Control plot*	*Winter plot*
Duff layer	4.8	5.5
Inorganic soil	5.2	5.2

Table V. Soil moisture (%)*, one day after winter oil treatment.

Soil layer	*Control plot*	*Winter plot*
Duff layer	295	154
Inorganic soil	56	70

* Mean of 3 replicate determinations.

NSO fractions. Physical analysis of the Prudhoe Bay crude oil used in this study is shown in Figure 9.

Oil/snow samples were also collected 1 hour and 24 hours after the spill. It was of interest to investigate the rate of loss of the volatile fraction of the oil after the spill. The oil/snow samples as well as the original oil were subjected to headspace analysis to determine if significant loss of these volatiles occurred rapidly at the low temperatures present during the spill. Headspace analysis of the original oil by gas chromatography indicated volatile components as light as methane to be present in measurable quantities. The sample exposed to the atmosphere for one hour following the spill prior to collection indicated a loss of the methane component and a reduction of C_2, but little change in C_3 and above. The 24-hour sample indicated almost total loss of the C_2 component, 70% reduction of C_3, and 50% loss of C_4, but little change at C_5 and above. The major components of the volatile fraction were considerably more persistent in the spilled oil than expected, due undoubtedly in large part to the temperature.

Fractionation of the oil/snow samples, as well as the oil extracted from soil cores into alkanes, aromatics, asphaltenes, and NSO's, as well as gas chromatography of these fractions, will be accomplished in the next quarter. Initial analysis of the oil for the fatty acid component will also be completed for comparison with samples collected later after prolonged exposure to the environment.

Vegetative analysis

Photographs were taken at the time of the winter spill to document the extent of visible oil contamination. Later observations after snowmelt were made to delineate the area of the visible oil. Oil covered all the mosses and lichens between the *Eriophorum* tussocks, and standing water was present in many of the oil-contaminated troughs. It was too early in the season to discern any leaf growth, but it was noted that at least some of the *Eriophorum* tussocks which were surrounded by oil in the troughs were flowering. Several photographs were also taken at this time.

Summary

Sites for summer and winter crude oil spills were designated, described, and instrumented during the first year of this project. The area was sampled for background information (soils, vegetation, microbiology, thermal) to monitor changes that might occur following the application of crude oil.

Crude oil was obtained from Prudhoe Bay, Alaska, moved onto the site, and heated to 60°C (140°F) to correspond to Trans-Alaska pipeline oil temperatures.

The winter spill of 2000 gallons (7570 liters) was conducted on 26 February 1976. Oil was applied on a 5-m (16½-ft) front. The oil melted the snow in the immediate area of application, then moved into the organic layers and followed the frozen microrelief of the site, moving downslope under the snowpack. Flow patterns and rates were established, thermal changes monitored, and chemical and microbiological samples obtained for analysis.

Thus far soil pH of the organic layer has increased and soil respiration has decreased within the winter spill plot. Chemical analysis showed a 25% loss of the oil in the form of volatiles after application; however, the major components of the volatile fractions were more persistent than theorized, probably because of the low temperature at the site of the spill.

Early spring observations indicate vegetative kill where oil had inundated the root zone or had been in considerable foliage contact.

Future plans

The summer crude oil spill was conducted during the week of 11 to 17 July 1976. Chemical, microbiological, thermal, and vegetation sampling will be conducted according to schedule to monitor fate and effect of the crude oil as applied to both the winter and summer spill plots. In addition, flow rates and patterns will be continually updated.

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